STUDIES
IN
THE CONSTRUCTION OF DAMS:
EARTHEN AND MASONRY.

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THE CONSTRUCTION OF DAMS:

EARTHEN AND MASONRY.

ARRANGED ON THE PRINCIPLE OF QUESTION AND ANSWER FOR ENGINEERING STUDENTS AND OTHERS.

BY

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PREFACE.

This little book is intended to be of assistance to Engineering Students who may be preparing for the "Associate Membership" Examination of the Institution of Civil Engineers, the Examination of the Institution of Municipal and County Engineers, the B.Sc. (Engineering) of our Universities, or other similar Exams. The text takes the "Question" and "Answer" form, which has been found by experience to be a most useful method of disciplining the mind of the Student to grasp essential teaching and at the same time learn how to express his knowledge. The matter is dealt with in a manner suited to fundamental principles, and the numerous diagrams form an integral part of the studies.

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University College,
University of London,
March, 1919.

SYMBOLS AND ABBREVIATIONS.

The following nomenclature is employed throughout this work :—

τ = weight in lbs. of a cubic foot of water (62·5), or in cwts. (0·557).

τ' = weight in lbs. of a cubic foot of mud, 85.

$\Delta\tau$ = weight in lbs. of a cubic foot of masonry.

H = head of water in feet.

h_1 = head of water above the liquid mud level.

h_2 = head of liquid mud.

ϕ = the angle that the water-face of the dam makes with the vertical.

E_τ = thrust of earth back fill in lbs.

δ = angle that E_τ makes with horizontal.

β = angle R makes with the vertical.

f = the co-efficient of friction for masonry on masonry (usually 0·6 to 0·75).

$P = \dfrac{\tau H^2}{2}$ = the horizontal static thrust of the water in lbs.

$W = A\Delta\tau$ = the total weight in lbs. or cwts. of masonry in a 1-foot length of the wall.

R = the resultant of P and W.

THE

CONSTRUCTION OF DAMS:

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QUESTION 1.—A masonry dam, 20 feet high, 4 feet wide at the top, and 12 feet wide at the bottom, has its faces straight, the water face being vertical. Draw the line of thrust when the water level is 2 feet from the top. Take the specific gravity of the masonry as 2·25. (Inst. C.E. Exam. Question.)

Answer.—The dam under consideration is illustrated in Fig. 1, which is drawn to a scale of 8 feet to 1 inch, the force diagram being to a scale of 100 cwts. to 1 inch.

The total water pressure on the wall varies as the head, and may be represented by the area of the triangle A B C. In a low dam B C may be taken as being equal to A B, although it really measures less. The centre of pressure passes through the centre of

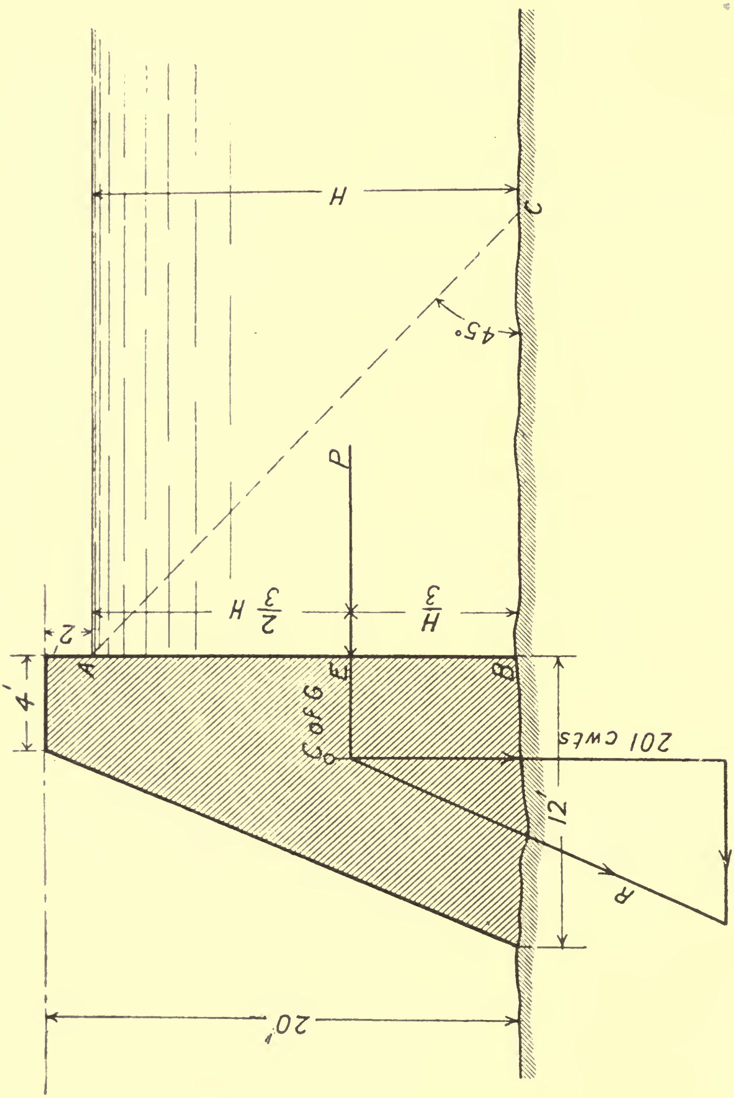


Fig. 1.—Scale, 8 feet = 1 inch. Force diagram, 100 cwts. = 1 inch.

gravity of this triangle, and occurs at E, so that A E = $\frac{2}{3}$ A B, and, if we consider a strip of the wall 1 foot wide, the resultant pressure P will be as follows :—

$$P = \frac{r^b H^2}{2},$$

where P = the normal pressure ;

r = the weight of a cubic foot of water

= 62·5 lbs.

= 0·557 cwt.;

H = head in feet,;

b = the constant breadth of the strip = 1 foot.

In the case now being considered

$$P = \frac{0{\cdot}557 \times 1 \times 18^2}{2}$$

$$= \frac{0{\cdot}557 \times 18^2}{2}$$

$$= \frac{180{\cdot}468}{2}$$

$$= 90{\cdot}234 \text{ cwts., say } 90{\cdot}2 \text{ cwts.*}$$

So that we know the magnitude, point of application, and direction of P.

Let us now consider the line of thrust. The weight of the dam must first be ascertained, and we are told

* It is quite unnecessary for the student to use the last two decimals, seeing that both masonry and water may vary in density, and that when designing the dam the resultant is kept well within the middle third of the base.

that the specific gravity of the masonry of which it is to be built = 2·25; therefore

$$\text{Weight of wall} = \underset{\substack{\text{(Cub. ft. of} \\ \text{masonry)}}}{160} \times \underset{\substack{\text{(Specfic} \\ \text{gravity of} \\ \text{masonry)}}}{2{\cdot}25} \times \underset{\substack{\text{(Weight of} \\ \text{cub. ft. of} \\ \text{water)}}}{62{\cdot}5}$$

$$= 22{,}500 \text{ lbs., or } 201 \text{ cwts.}$$

The weight of the wall will act through the centre of gravity of the section. The resultant may be found graphically as shown in Fig. 7. It will be observed that R (the line of thrust) is well within the middle third of the wall, and, therefore, the structure is quite strong enough.

QUESTION 2.—Give a sketch of, and briefly describe, one or more important high masonry dams.

Answer.—Excellent examples of high masonry dams may be seen in this country, in America, France, India, Spain, and Australia.

Furen's Dam (France).—Fig. 2 illustrates a remarkable dam in France, known as Furen's Dam. Its base is 161 feet in width, and the depth of water impounded is 164 feet. The structure is 18 feet 9 inches in width at the top, and the dam is built upon a rock foundation. It is some years since this dam was constructed, and it shows no sign of failure. The maximum pressure on the dam is 6 tons per square foot only, which is very low seeing that engineers often reduce the dimensions of the structure so as to provide for a pressure of 9 tons per square

foot, while in America a working pressure of 14 tons per square foot has been allowed.

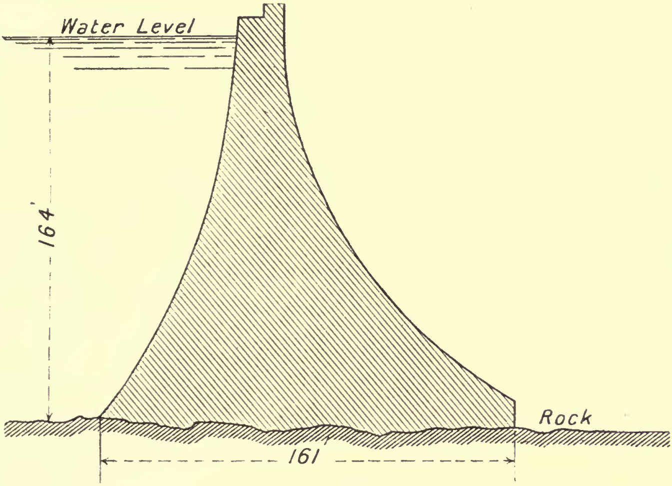


Fig. 2.

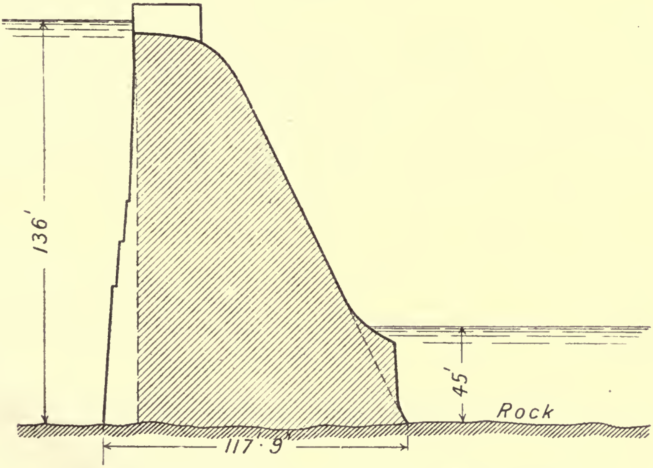


Fig. 3.—Vyrnwy Dam, Liverpool Waterworks.

Vyrnwy Dam (England).—This is an interesting example of dam construction in England (see Fig. 3).

The structure was erected a few years ago in connection with the Liverpool Waterworks. It is built upon a rock foundation, is 117 feet 9 inches in width at the base, and retains a depth of water of 136 feet on one side, and about 45 feet on the other. The late Sir Benjamin Baker, M.Inst.C.E. (ex-President, Inst.C.E.), was the consulting engineer in connection with this fine piece of engineering work.

Olive Bridge Dam (America).—This structure, which was completed in 1914, represents the latest important masonry dam which has been built, and is an excellent example of what may be done in the way of dam construction; it is one of the largest dams in the world, and is one of the main dams in connection with the New Water Supply Scheme for Greater New York (Fig. 4). Its length is 4,650 feet, height 220 feet, thickness at base 190 feet, and at top 23 feet. The width of the storage reservoir, which it retains, varies from 1 to 3 miles, and the maximum depth is 190 feet; the depth of the reservoir averages 50 feet. For the construction of this dam seven villages were submerged, 32 cemeteries had to be removed, and 2,800 bodies had to be reinterred. Eleven miles of railroad had to be relocated, 64 miles of highways discontinued, and 40 miles of new highways constructed.

Three million cubic yards of earth and rock had to be excavated, and over 8 million cubic yards of embankment to be placed, while the quantity of

masonry to be placed represented approximately 1 million cubic yards.

3,000 men were employed in the construction of this dam.

QUESTION 3.—(*a*) What forces operate on a masonry dam? (*b*) How may a dam fail? (*c*) How would you proceed to design a high dam?

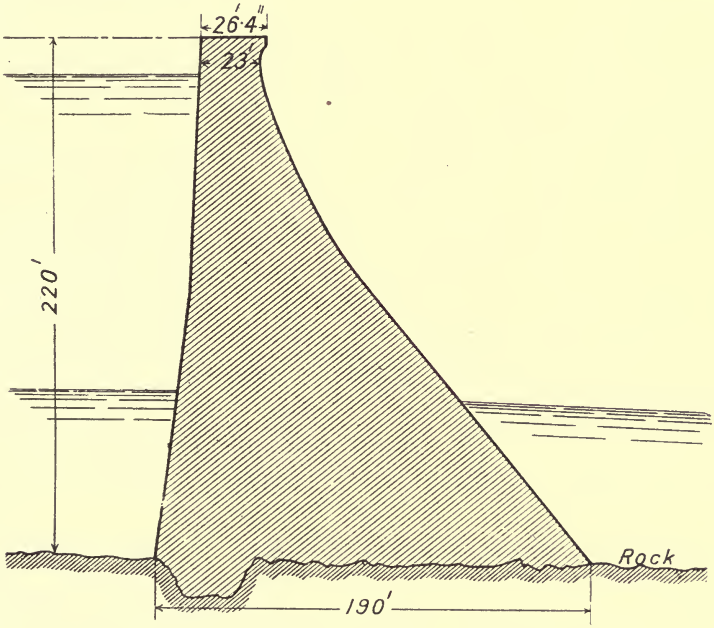


Fig. 4.—Olive Bridge Dam, U.S.A.

Answer.—(*a*) Reservoir dams are subject to two main pressures—a *vertical* pressure due to the weight of the dam, with its resultant passing through the centre of gravity of the structure, and a *horizontal* pressure, due to the water in the reservoir; both can

be calculated. When the reservoir is empty, the only pressure on the dam is that due to its own weight. In addition to these two main pressures, ice pressure may occur by the surface of the water becoming frozen and upward water pressure may occur at the base of the dam.

(*b*) There are four ways in which a dam may fail, they are as follows :—

(1) The structure may overturn about the edge of any joint, due to the resultant passing beyond the limits of stability.

(2) It may fail by the crushing of the masonry or foundation because of excessive pressure.

(3) By the sliding or stearing on the foundation or at any joint owing to the horizontal thrust being greater than the structure can withstand.

(4) By tension occurring at any joint and causing rupture at that joint.

(*c*) In designing a high masonry dam, we take a trial section, and divide this up into smaller sections, as shown in Fig. 5. We then proceed to find out whether the top section of the dam " No. 1 " is sufficiently strong to act as a low dam, holding up the depth of water shown. We calculate the weight of this portion of the dam, taking Δ_{τ} = weight in lbs. of a cubic foot of masonry, and the water pressure, and ascertain whether the resultant passes well within the middle third of the wall ; if it does not do so, we must increase the width of the base so that R

will come within the middle third of it. Having done this, we take Sections 1 and 2, and assume that these two sections combined form the dam. The centre of gravity of the two sections must be ascertained, the weight of the structure and the water pressure must be calculated, the centre of pressure acting at a point $\frac{H}{3}$ above base, where H = depth of

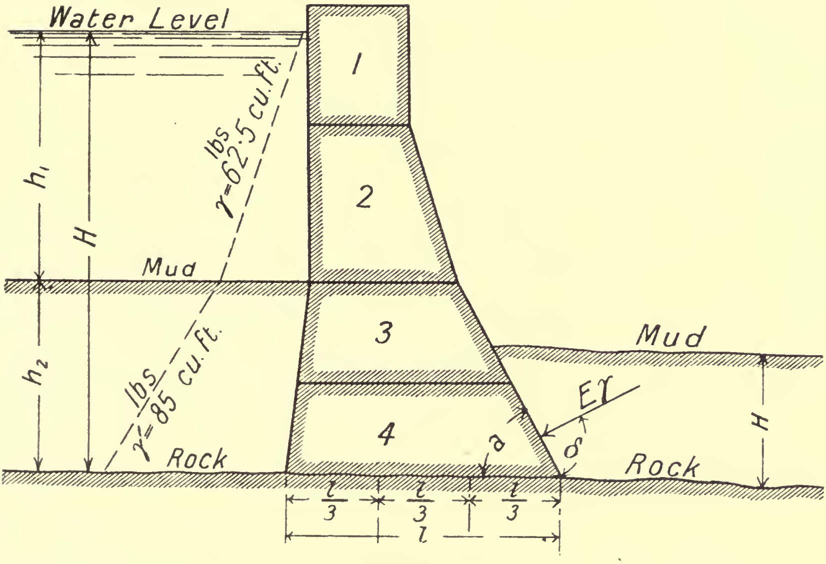


Fig. 5.

water or head. We can in this way divide the dam up into as many sections as we choose, and ascertain the strength of each section.

We proceed in the same way with Sections "Nos. 3 and 4," except that we now have, in addition to the water pressure due to a head of h_1 (see Fig. 5),

a mud pressure of h_2, and, whereas $\tau = 62{\cdot}5$ lbs. per cubic foot in the case of water, with mud $\tau^1 = 80$ to 90 lbs. per cubic foot, say 85 lbs.

We must also calculate the pressure on the back of the dam of the earth backfill, or mud, E_τ, the dam for this purpose may be treated as a battered-face retaining wall. While we should know what this back-pressure is, in designing the dam it is wise to make no allowance for it.

QUESTION 4.—A reservoir wall has been built too light in section, and it is proposed as a temporary measure to strengthen it by putting in a tie-rod. What is the best position for this tie-rod? And why? The reservoir is rectangular in plan.

Answer.—Fig. 6. Let the sketch A B C D illustrate the reservoir wall, and H the maximum depth of water. When a rigid plane is pressed upon by water, there is one point in that plane at which the resultant of all the pressures acts; this point is called the "centre of pressure," so that if a force is applied at the "centre of pressure" which is equal to the resultant P, then all the pressures against the wall will be counterbalanced, and the structure will be in equilibrium. The position of the "centre of pressure" in a rectangular figure immersed in water is at a point $\frac{1}{3}$ H from the base, measured up the centre line F E, so that it follows that when a tie-rod is to be put in extending across the tank from wall

to wall, its position should be where the "centre of pressure" occurs; this is shown in sketch as $P\ P_1$.

QUESTION 5.—A reservoir dam is 12 feet in height, 9 feet wide at the base, and triangular in shape, the water face being vertical; the weight of the masonry is 125 lbs. per cubic foot. When the reservoir is filled

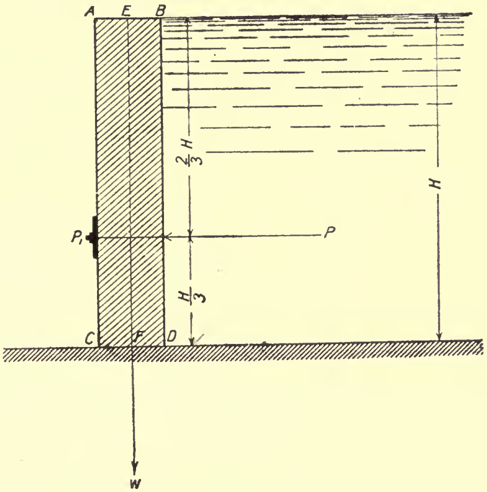


Fig. 6.

to the upper edge of the dam, find the point at which the resultant line of pressure intersects the base.

Answer.—The dam referred to is shown in Fig. 7, and also the point at which the resultant cuts the base. This resultant is arrived at as follows:—The total water pressure on the dam is represented by the area of the triangle A C D, and the resultant pressure passes through the centre of gravity of this triangle,

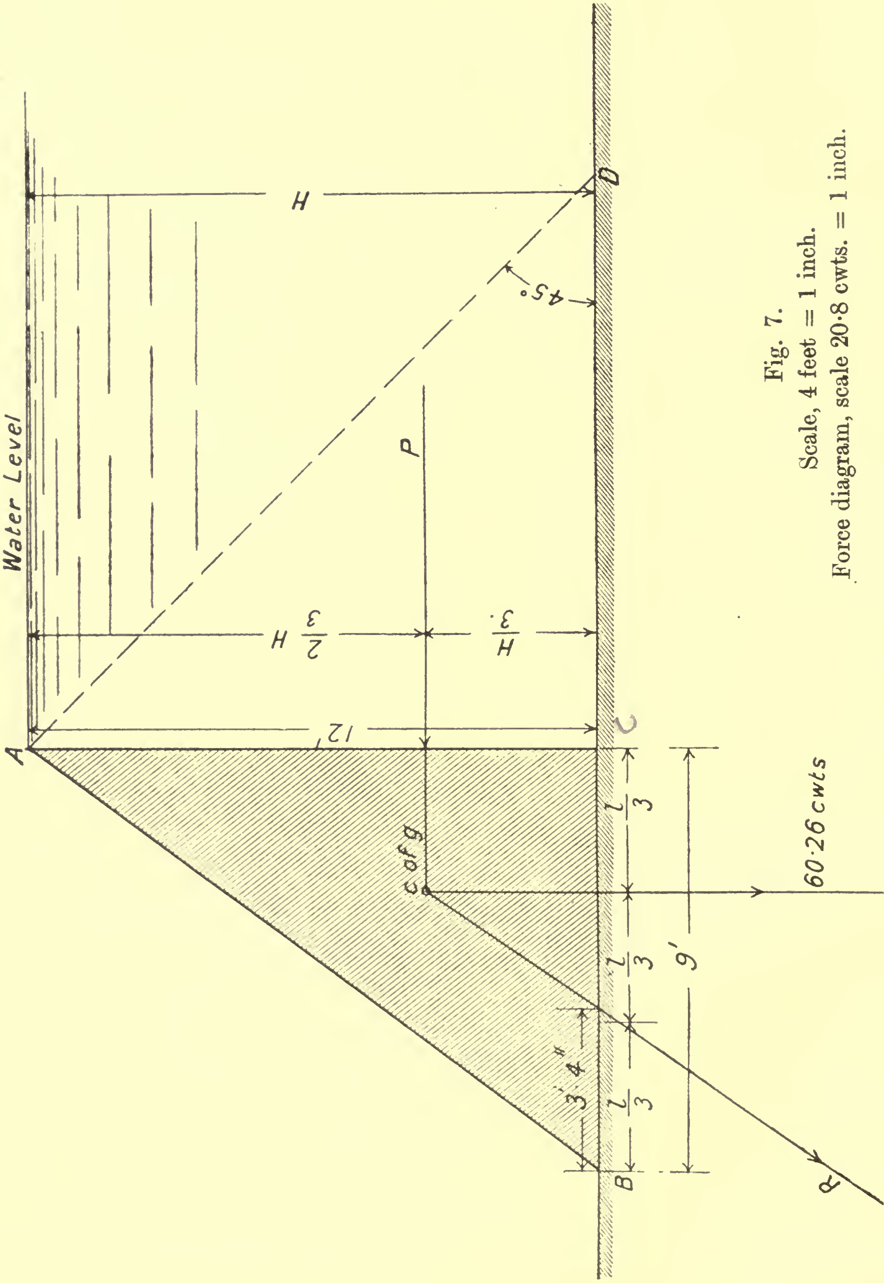


Fig. 7.
Scale, 4 feet = 1 inch.
Force diagram, scale 20·8 cwts. = 1 inch.

and acts at P, so that if we consider a 1-foot length of the wall—

τ = the weight per cubic foot of water
= 62·5 lbs., or 0·557 cwt.

b = a 1-foot strip of wall,

the volume of the prism will be

$$\frac{A\,C \times C\,D}{2} \times 1 = \frac{A\,C^2}{2} = \frac{H^2}{2}.$$

$$\therefore \qquad P = \frac{\tau\, b\, H^2}{2}$$

$$= \frac{0{\cdot}557 \times 1 \times 12^2}{2}$$

$$= 0{\cdot}557 \times 72 = 40{\cdot}1 \text{ cwts.}$$

The weight of the wall is to be taken as 125 lbs. per cubic foot.

The cubic contents of one foot of wall being

$$\frac{A\,C \times C\,B}{2} \times 1 = \frac{12 \times 9}{2} \times 1 = 54 \text{ cubic feet.}$$

Weight of dam 54 × 125 = 6,750 lbs., or 60·26 cwts. The resultant R cuts the base within the middle third of the dam—namely, at a point 3 feet 4 inches from the outer edge of the dam B.

Question 6.—How would you ascertain the water pressure on the face of an embankment? Illustrate your answer by a sketch.

Answer.—The water pressure on E D, the face of the embankment (see Fig. 8), for each foot of the

structure, is represented by the area of the triangle E D F × 1 foot. This force P will act through the

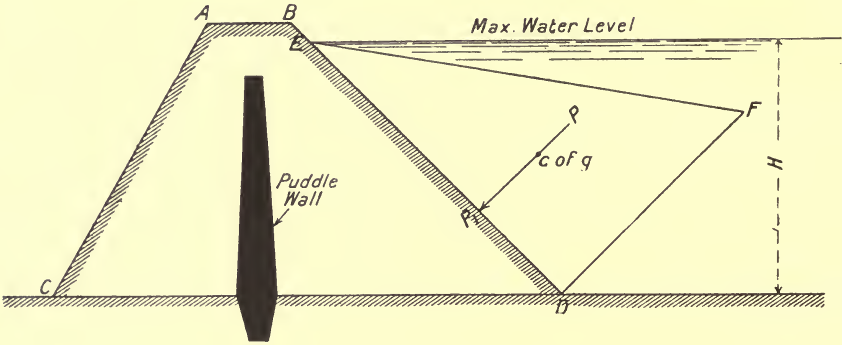


Fig. 8.

centre of gravity of the triangle at a point P_1. D F = H. As the area of a triangle is equal to its base

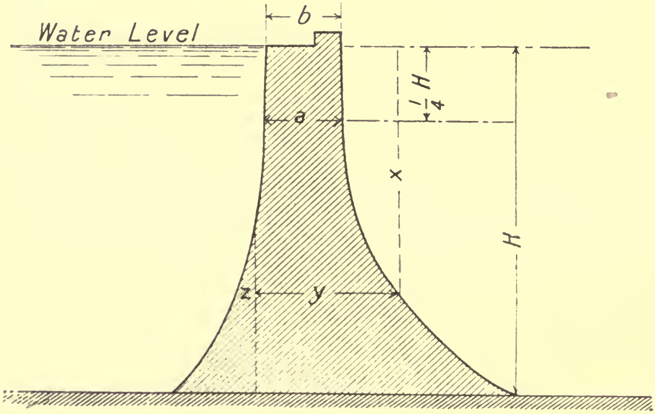


Fig. 9.

multiplied by half its height, and the weight of water is taken as 62·5 lbs. per cubic foot, then, if the measure-

ments are taken in feet, the pressure on the embankment will be

$$\frac{E D \times D F}{2} \times 62 \cdot 5 = E D \times D F \times 31 \cdot 25 \text{ lbs.}$$

The resisting weight will be the sectional area of the embankment, multiplied by its weight per cubic foot.

QUESTION 7.—What are the suggestions made by Molesworth relative to the thickness of high and low masonry dams ?

Answer.—Molesworth's general rule regarding the thickness of high masonry dams is as follows :—

High Masonry Dams (see Fig. 9).—

Let H = height of dam in feet.

x = any depth below surface of water in feet.

y = offset from vertical line to outer face of dam at any depth x in feet.

z = offset from vertical line to inner face in feet.

b = width of dam at top in feet.

a = width of dam at $\frac{1}{4}$ H from top in feet.

P = limit of pressure allowed on the masonry in tons per square foot, say, 9 tons, as in the case of the La Terrasse dam.

Then $$y = \sqrt{\frac{\cdot 05\, x^3}{P + (\cdot 03\, x)}}.$$

$$z = \left(\frac{\cdot 09\, x}{P}\right)^4.$$

$$b = 0 \cdot 4\, a.$$

If y as given by the formula be less than $0{\cdot}6\,x$, it must be increased to $0{\cdot}6\,x$.

Low Masonry Dams.—Molesworth also gives a useful general rule for use in the designing of low masonry dams, and one that it is possible to remember. It is as follows :—

Minimum Thickness.

Let T = minimum thickness of dam at any depth "d" below the surface of the water.

g = specific gravity of the masonry.

= for light masonry, 130 lbs. per square foot = 2·08.

= for ordinary masonry, 140 lbs. per square foot = 2·24.

= for heavy masonry, 150 lbs. per square foot = 2·40.

d = depth below surface of water.

Then $$T = 1{\cdot}5\,\frac{d}{\sqrt{g}}$$

Another general guide as to the thickness of a low masonry dam is as follows :—

Width at bottom = height × 0·7.
Width at middle = height × 0·5.
Width at top = height × 0·3.

This is illustrated in Fig. 10.

Question 8.—Sketch and describe the construction of an earthen embankment. Set out in detail how you would proceed to build the puddle wall.

Answer.—The embankment is illustrated in Fig. 11; the method of constructing this is as follows:—A very careful selection of the site having been made,

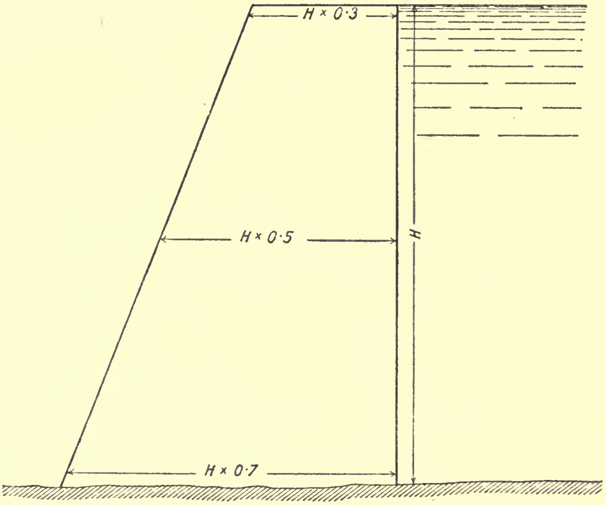


Fig. 10.—Molesworth's Suggestion.

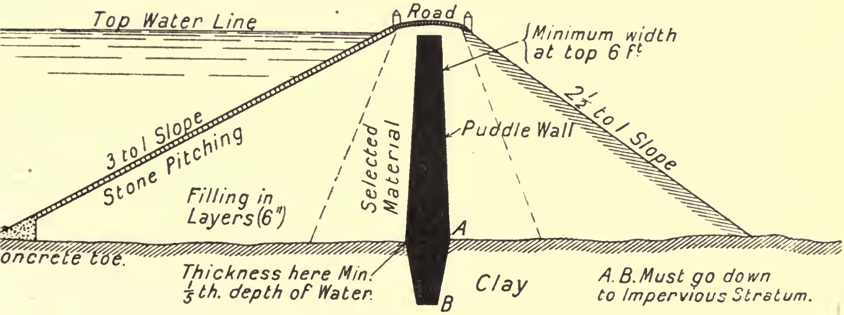


Fig. 11.

after trial shafts and boreholes have been sunk, the position for the puddle wall should next be fixed;

this is usually about the middle of the embankment. It must be carried down to an impervious strata, compact clay being an ideal foundation for the dam, and as to its dimensions, it should not be less in thickness at the ground level than one-fifth the depth of water to be impounded, and should be a thickness at the top of 6 feet or more. The puddle wall should be carried up above the highest water level, and before its construction is commenced the trial shafts should be plugged with puddled clay. The height that the dam is required to be will decide its length. No part of a dam requires more care in constructing than the puddle wall. The location of this, and its dimensions and height having been fixed, the puddle trench is excavated. It is usual to taper this, and to batter the faces of the wall above, as shown in the sketch, the reason for this tapering being that the clay below original ground level becomes more compressed than in the upper part of the puddle wall, and owing to the narrowing of the wall at the extreme bottom the clay becomes even more compact. Making the wall of greater thickness at ground level than at the top increases the weight on the tapered portion below ground level.

Should any streams be met with when excavating the puddle trench, these must be carried by pipes to the down-stream toe of the embankment.

In longitudinal section the puddle wall should be constructed in the manner shown in Fig. 12, the clay

being cut out in steps, and a bye-wash put in near the top of the embankment.

The clay used should be exposed for some time after being cut in pieces, and must then be ground in a pug-mill, from whence it is taken to the trench, put in in layers not exceeding 6 inches in thickness. It is worked into a plastic mass by being trodden on repeatedly by the workmen, and it is cut up by the men, who use narrow spades for the purpose. The surface should be kept moist by the addition of water, too much of which is undesirable. Should the puddle

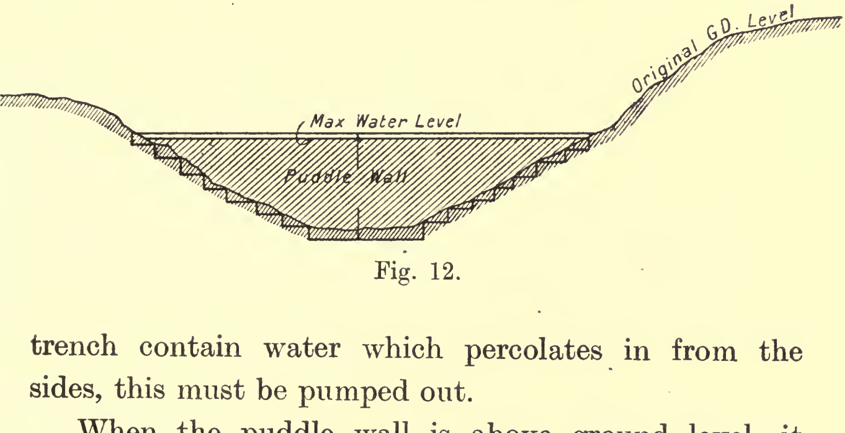


Fig. 12.

trench contain water which percolates in from the sides, this must be pumped out.

When the puddle wall is above ground level, it must be supported by tipping selected filling in 6-inch or 9-inch layers on both sides of it; this filling may be quarry spoil, or clay, or other selected material, and should be so placed that its weight will assist in holding up the wall (see Fig. 13). The filling should be well watered, and rolled with a heavy roller; sometimes a steam roller is used. Before this filling is placed,

the soil on the original ground for a depth of, say, 8 or 9 inches should be removed; this will be used again later to cover the outer slope of the embankment. This "selected" filling having thus been placed, the remainder of the filling is then put on in layers and well rolled.

A batter of 3 to 1 on the water face and 2 or $2\frac{1}{2}$ to 1 on the outer slope would be satisfactory. The inner slope should be stone-pitched, or paved with concrete slabs, and a rubble masonry or concrete

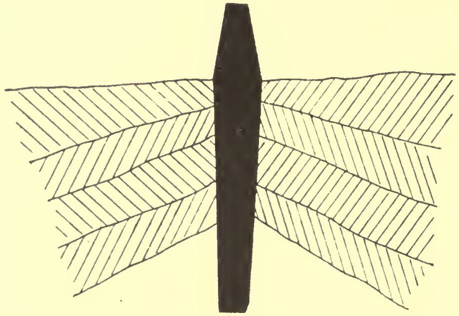
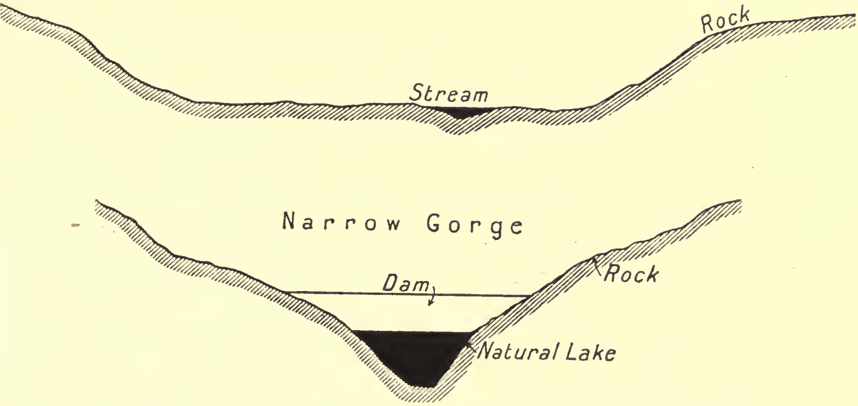


Fig. 13.

(6 to 1) toe is advisable. A road is sometimes constructed on top of the bank, and the width of the bank at this point may be anything from 7 to 20 feet; it should not generally exceed 16 feet. The height above the surface of water of the top of the embankment should not be less than, say, 4 feet.

QUESTION 9.—Say what you consider to be an ideal site for a large storage reservoir, and why? Illustrate your answer by a sketch.

Answer.—The selection of the site for an impounding reservoir is a matter of the greatest importance. One of the best sites it is possible to choose is one in which there is an impervious stratum, such as compact clay or close-grained rock free from fissures. A site where there is no possible likelihood of the water becoming contaminated, and one where there is a large watershed, and where there is a wide and flat valley draining into a stream, the valley extending for a considerable



Figs. 14 and 15.—Ideal Site for Storage Reservoir.

distance, and, at its lowest level, ending in a narrow and deep gorge, where there is a natural lake, and where a dam can be constructed at a fairly low cost, and the level of the lake raised to any required height, would be very suitable. These conditions are shown in Figs. 14 and 15. It is assumed that the town to be supplied with water lies at a much lower level than the site for the storage reservoir shown in the illustration.

QUESTION 10.—What is the amount of storage necessary to amply provide for a period of excessively dry weather? Describe two notable examples of the use of lakes as storage reservoirs in connection with the water supply of towns.

Answer.—120 to 250 days' supply should be allowed for, according to the rainfall of the district; the first figure may be taken in a wet district, and the second if the district is dry.

Two notable examples of the use of existing lakes as storage reservoirs are Loch Katrine and Thirlmere. In both instances the water level in the lake was raised by building a dam across the valley. Loch Katrine has an area of 3,119 acres, and the water level was raised 4 feet, and assuming a shrinkage of 3 feet below its original level to allow for an excessively dry period, then the minimum quantity of water stored is 5,687 million gallons. Glasgow is thus provided with 50 million gallons per day of water, and works are now in progress which, when completed, will double this amount.

This huge storage reservoir is 34 miles from Glasgow.

Thirlmere supplies Manchester, although it is situated 100 miles from that city. The service reservoir is 4 miles outside the city, and there is a fall between the impounding and service reservoirs of 2 feet per mile.

The lake was raised by the construction of a concrete dam faced with masonry. The structure is built on the solid rock, and is carried up to a height of 57 feet above the former level of the lake.

QUESTION 11.—(*a*) Sketch and describe an earthen embankment, where, instead of putting in a puddle wall, a rubble masonry core has been constructed. (*b*) What objection is there to this form of construction ?

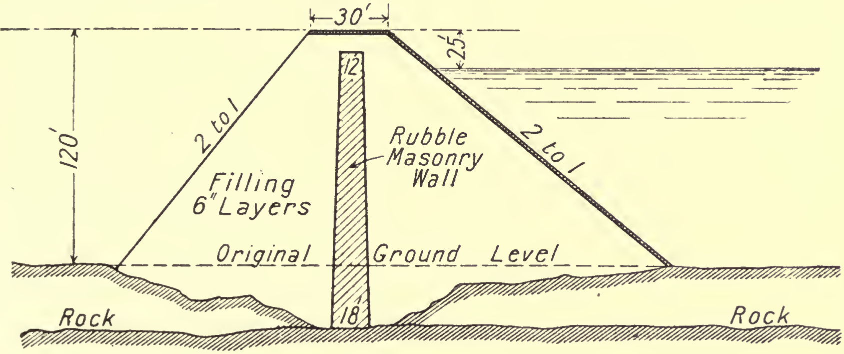


Fig. 16.

Answer.—(*a*) There are several examples in America of earthen dams constructed on this principle, but very few in this country. Fig. 16 illustrates an American example. This dam was constructed briefly as follows :—The centre line of the dam having been fixed, a trench was excavated down to the solid rock, and much of the original ground was also excavated, as shown in Fig. 16. The rubble masonry wall was then built upon this rock foundation ; there was plenty of stone in the district for this wall. This

core wall was 18 feet in thickness at the base, and 12 feet at the top, and was carried up above maximum water level. As the building of the wall proceeded, the filling, in 6-inch layers, was added; this nearly kept pace with the wall, and was well watered and rolled. The dam is 30 feet wide at the top, and the slopes are steeper than is usual—namely, 2 to 1. The water-face is pitched, and the height of the dam above original ground level is 120 feet, the depth of water retained being 95 feet.

(*b*) Rubble walls have the disadvantage often of leaking badly, whereas puddle walls do not err in this respect. They are usually more expensive than puddle walls. Their use, however, can be recommended where clay is not to be found in the district where the dam is to be constructed, but good stone is plentiful, and a rock foundation is available. Under these circumstances, however, a concrete wall is preferable, although this is more costly than rubble.

QUESTION 12.—What circumstances would guide you in your decision as to whether a dam should be of masonry or whether an earthen embankment should be constructed?

Answer.—Where clay and filling in a district is scarce (especially the former), but there is a good rock foundation for the dam, and plenty of available stone, and the structure is to be 80 feet or upwards

in height, a masonry dam should be constructed. If the dam is to be less than 80 feet high, and is to be built on a clay foundation, an earthen embankment will be found to be cheaper, and quite as useful.

QUESTION 13.—How would you find (*a*) the centre of gravity of a triangle, (*b*) the centre of gravity of a parallelogram, and (*c*) co-ordinates of the centre of gravity in a figure ?

Answer.—(*a*) The centre of gravity in a triangle

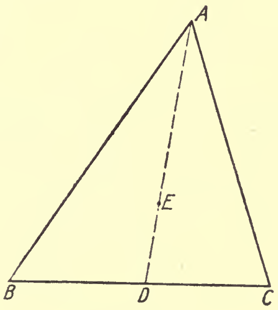


Fig. 17.

is found by bisecting the base B C at D (see Fig. 17), joining A D, and finding a point E which is one-third A D. In an equilateral triangle the centre of gravity is its centre.

(*b*) The centre of gravity of a parallelogram lies at the intersection of its diagonals ; this does not apply to other four-sided figures ; for instance, in

Fig. ~~18~~ 19 it is clear that the intersection of the

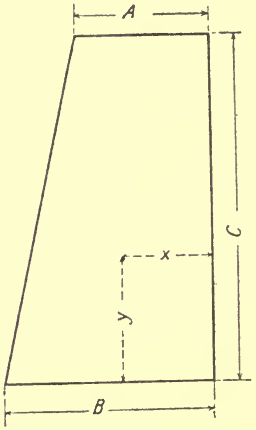


Fig. 18.

diagonals is nowhere near the centre of gravity of the figure.

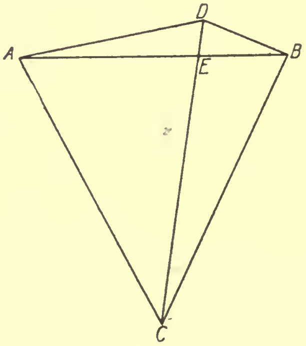


Fig. 19.

(*c*) Co-ordinates of the centre of gravity in a figure (see Fig. ~~19~~) may be found as follows :—

18

$$x = \frac{1}{3}\left(A + B - \frac{A\,B}{A + B}\right).$$

$$y = \frac{C}{3}\left(\frac{2\,A + B}{A + B}\right).$$

QUESTION 14.—Sketch and describe a low reinforced-concrete dam. How would the strength of this be calculated ?

Answer.—Fig. 20 illustrates such a dam. It consists of a reinforced-concrete slab 6 inches in thickness,

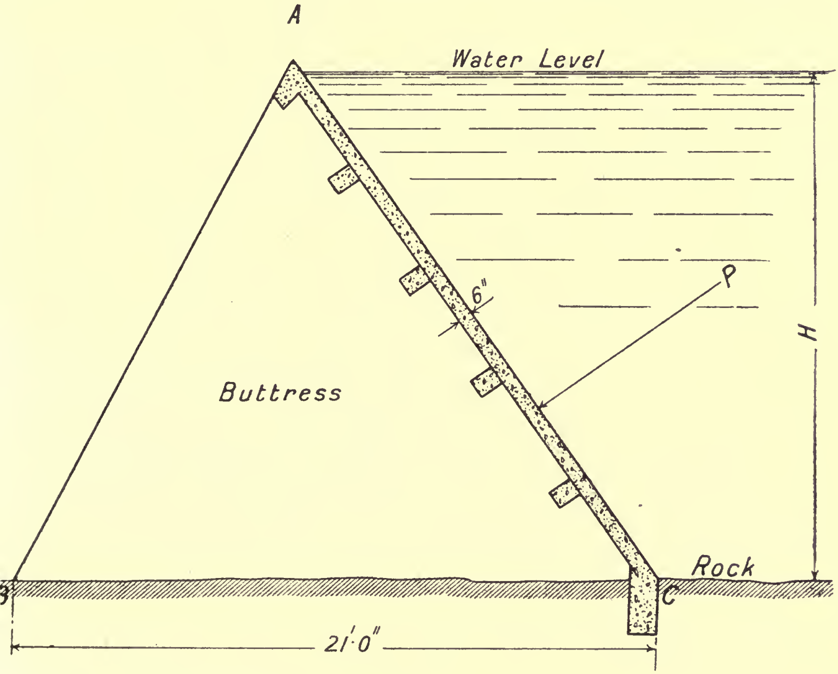


Fig. 20.

supported by R.C. beams, and plain concrete buttresses, say, 14 inches in thickness, spaced at 6-foot centres; the concrete throughout this structure is in the proportions of 1 : 2 : 4—namely, 1 of Portland cement, 2 of sand, and 4 of broken stone, suitable for

passing through a $\frac{3}{4}$-inch ring for the reinforced work, and through a 1-inch ring for the buttresses. A toe must be constructed into the rock as shown, to prevent water getting under the structure. The reinforcement throughout will consist of steel rods, varying in size according to the depth of water. The working stresses of the materials used will be as follows :—

	Lbs. per Sq. Inch.
Concrete in compression, .	600
Adhesion of concrete to metal,	100
Concrete in shear in beams,	60
Steel in tension, . .	16,000

(Assuming that the steel has a tenacity of not less than 60,000 lbs. per square inch.)

The dam is built on the solid rock, and its height is 16 feet above the rock surface.

In arriving at the strength of this structure it must be noted that all the buttresses have to do is to resist a compressive stress ; there is no need for these to be reinforced. Three things must be known before we can design these buttresses :—

(1) The amount of the resultant thrust due to the water pressure, the centre of pressure being at P. The water pressure will vary from zéro at A to a maximum at C.

(2) The weight of the beams and slab resting on these buttresses.

(3) The weight of the buttresses themselves.

As to the beams and slab, these can easily be calculated, for they will be treated as ordinary floor beams and slabs, except that instead of the B M $= \frac{W\, l}{8}$, as in the case of a load equally distributed, and the shearing force $= \frac{W}{2}$, the loads on the beams and slab will vary in proportion to the depth of water. Their own weight must also be taken into account, and the weight of the reinforcement. It is usual to allow for the weight of concrete + the weight of reinforcement to weigh 150 lbs. per cubic foot.

QUESTION 15.—In the practical designing of a masonry dam, the shape arrived at theoretically is often improved; give an illustration of this, and show by a sketch what you mean.

Answer.—An instance of this is shown in Fig. 21, which represents the outline of a triangular-shaped dam. Theoretically the portion of the dam which is not hatched represents a structure which is quite capable of holding up the water H in the reservoir, but the engineer by using a little more concrete improves on the shape of this dam by the addition of the portions hatched. The resultant thrust, it will be observed, passes through the middle third of the base, which it did before the base was widened.

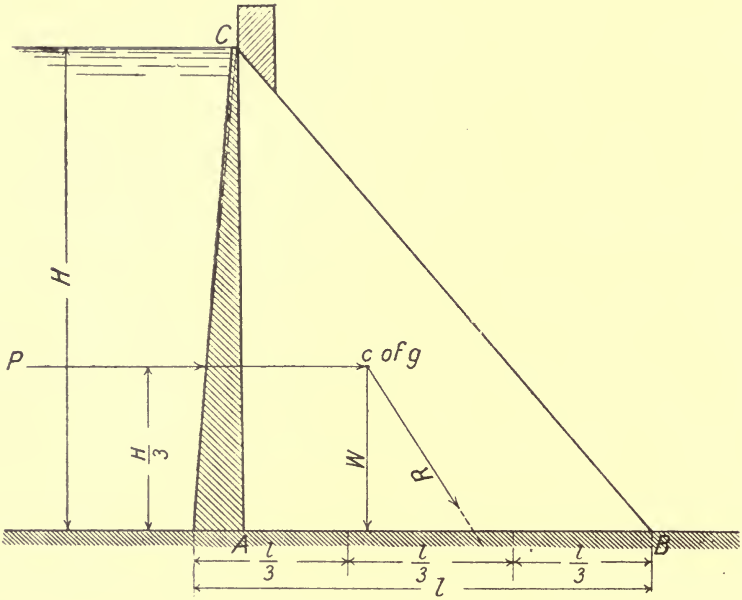


Fig. 21.

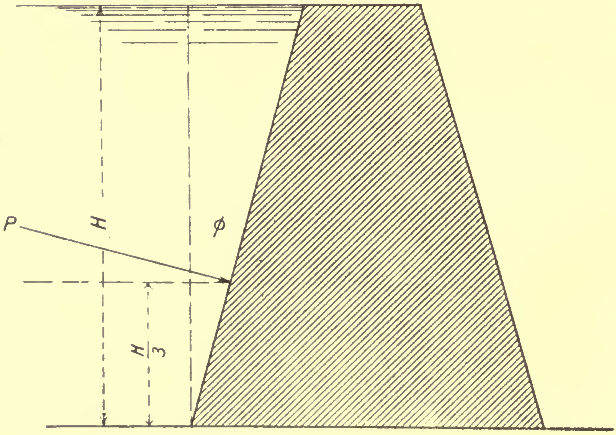


Fig. 22.

QUESTION 16.—Give a formula for ascertaining the total pressure on a dam where the water face is battered.

Answer.—The usual formula is—

$$P = \frac{\gamma H^2}{2} \sec \phi.$$

ϕ = the angle that the water-face of the dam makes with the vertical.

H = distance H (in feet) below the surface.

P = total pressure on the dam acting at a point $\frac{H}{3}$ from bottom.

Resolved horizontally and vertically, we have—

$$\text{Horizontal component} = \frac{\gamma H^2}{2},$$

$$\text{Vertical component} = \frac{\gamma H^2}{2} \tan \phi.$$

QUESTION 17.—Give a formula for ascertaining the pressure acting on a submerged dam.

Answer.—Let Fig. 23 represent the submerged dam. The pressure on this dam is represented by the formula

$$P = \gamma H (d + \tfrac{1}{2} H) = \frac{\gamma H}{2} (H + 2d);$$

the "centre of pressure" is at a distance below the surface of the water of

$$\frac{2}{3} \frac{(H + d)^3 - d^3}{(H + d)^2 - d^2},$$

so that above the base it will be

$$\frac{\mathrm{H}}{3} \cdot \frac{\mathrm{H} + 3\,d}{\mathrm{H} + 2\,d}.$$

QUESTION 18.—Design a masonry dam to impound a depth of water of 90 feet; show that the dam is sufficiently strong. Illustrate your answer by a section through the dam, drawn to scale.

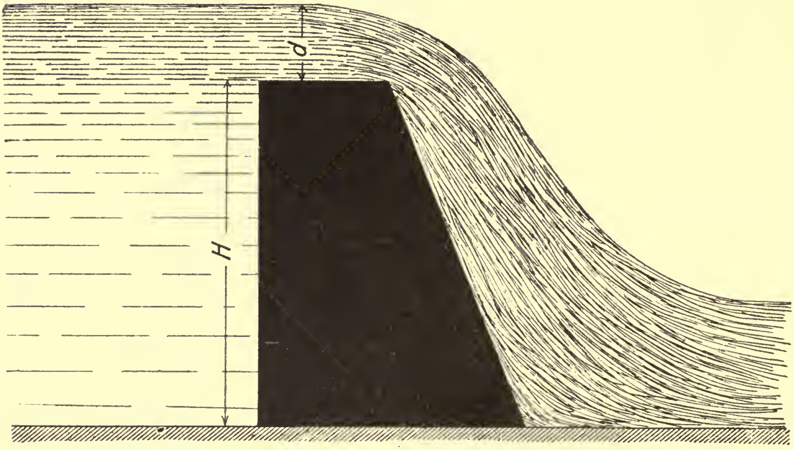
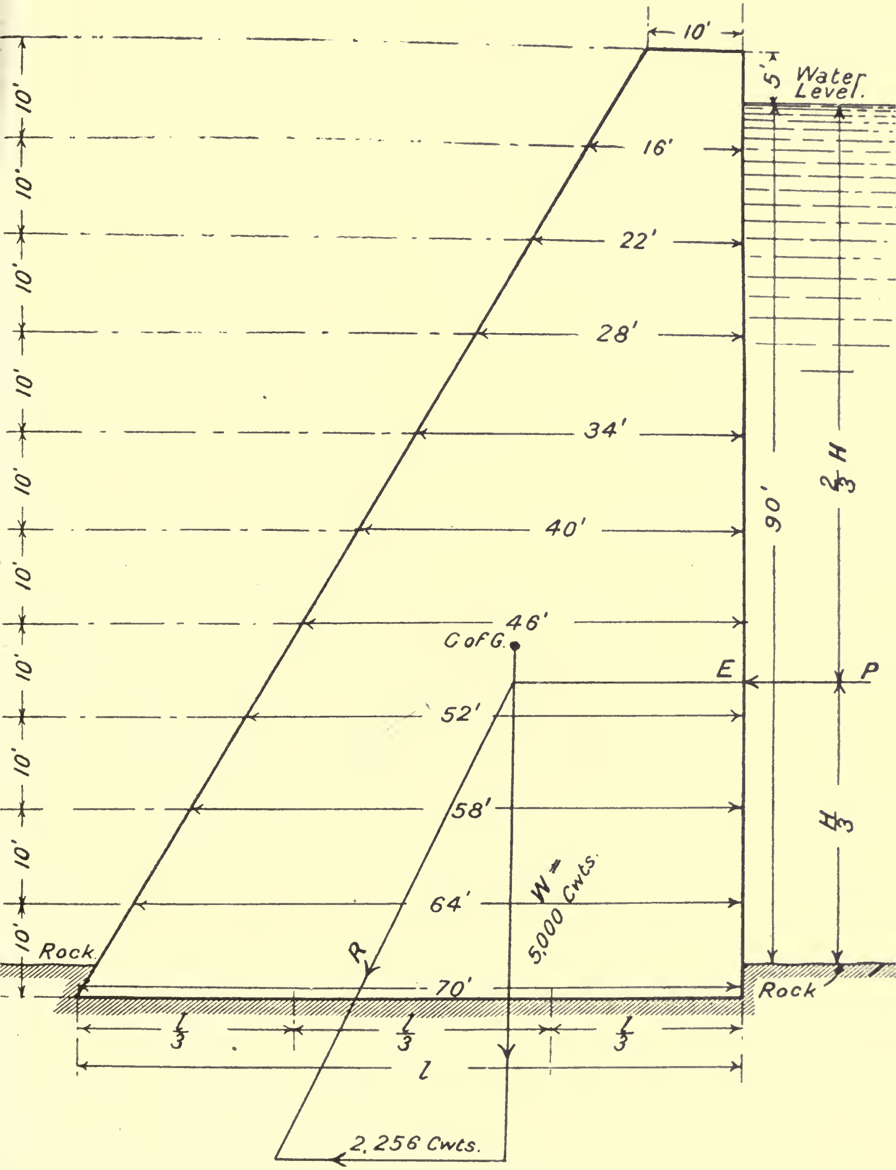


Fig. 23.

Answer.—The dam as designed is illustrated in Fig. 24. It is 70 feet wide at the base, the foundations being 5 feet into the solid rock. The top of the dam, which is 10 feet in width, is 5 feet above maximum water level. The structure has a vertical water-face, and sloping back, and its full height is 100 feet.

If the dam is divided up into sections, each being 10 feet deep as shown in the sketch, and the centre



Scale, 20 feet = 1 inch.
Force diagram, 2,000 cwts. = 1 inch.

Fig. 24.

of gravity of each section, also the weight of the individual section, and the water pressure on that section ascertained, it will be found that each section is sufficiently strong to resist the water pressure. As a check on this, the position of the centre of gravity of the whole mass is shown, and the weight of the structure has been calculated, and the water pressure, the result being that the line of thrust falls well within the middle third of the dam, so that the structure is quite adequate in strength.

The calculations are as follows :—

$$\text{Resultant pressure P} = \frac{\gamma\, b\, H^2}{2}$$

$$= \frac{0{\cdot}557 \times 90^2}{2}$$

$$= \frac{0{\cdot}557 \times 8{,}100}{2}$$

$$= 2{,}256 \text{ cwts.}$$

Weight of Dam (W).—Assume that the masonry $= \Delta\,\gamma = 140$ lbs. per cubic foot ; there are 4,000 cubic feet of masonry in the dam ; therefore the weight of the structure = 5,000 cwts.

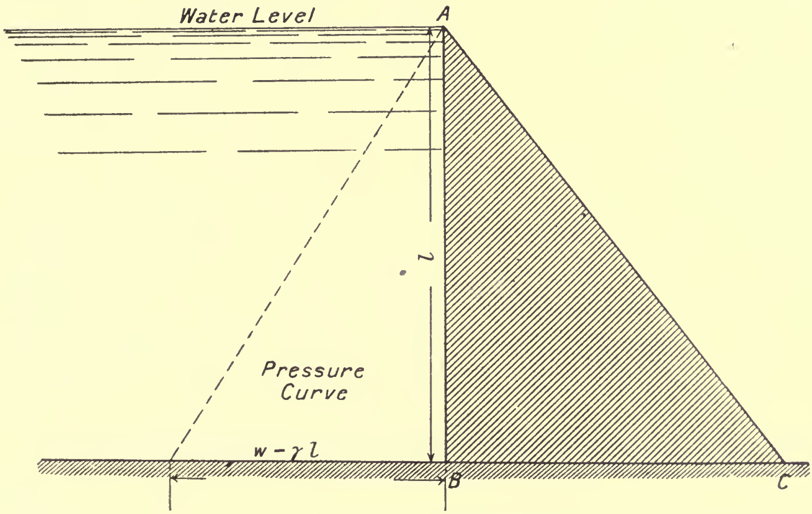
P and W are set out to scale in the force diagram.

QUESTION 19.—What is theoretically the most economical shape for a dam ? And why ?

Answer.—The most economical shape for a dam is a figure the shape of a triangle, and the nearer practical

conditions will allow of the dam being of that shape the better. This is the best, because water pressure varies from zero at A (see Fig. 25) to a maximum at B, and the dam is proportionate in thickness to the pressure.

QUESTION 20.—What minimum width at the base should a dam of triangular section be, in order that the resultant pressure R may fall just within the middle



w = the pressure per unit area.

l = the head.

Fig. 25.

third of the base (two-thirds of its thickness from the inner face), and that the limiting intensity of pressure may not be exceeded. The specific gravity of the masonry may be taken as 2·00.

Answer.—Let t = the width at base,

H = the height of the dam in feet.

Δ = the specific gravity of masonry, say 2·00,

and we will assume that the dam is 30 feet high.

Then
$$t = \frac{H}{\sqrt{\Delta}}$$
$$= \frac{30}{\sqrt{2 \cdot 00}} = \frac{30}{1 \cdot 414} = 21 \cdot 216 \text{ feet.}$$

If the base of the structure is made 21·216 feet wide, the resultant pressure R will just fall within the middle third (see Fig. 26), and the dam can safely be 30 feet in height.

If, on the other hand, we had the width of base given, but required to know to what maximum height the dam could have safely been carried to comply with the conditions before-named, we should have arrived at this, as follows :—

$$H^2 = \Delta t^2.$$
$$\therefore \quad H = t\sqrt{\Delta}.$$

So that, given width of base as 21·216 feet,

$$H = t\sqrt{\Delta}$$
$$= 21 \cdot 216\sqrt{2}$$
$$= 21 \cdot 216 \times 1 \cdot 414$$
$$= 30 \text{ feet.}$$

Now as to the intensity of pressure. We will assume that the stresses on the base are parallel to

the resultant (see Fig. 26), the maximum intensity of pressure being on a plane C D at right angles to R. Then the intensity on the horizontal base B C

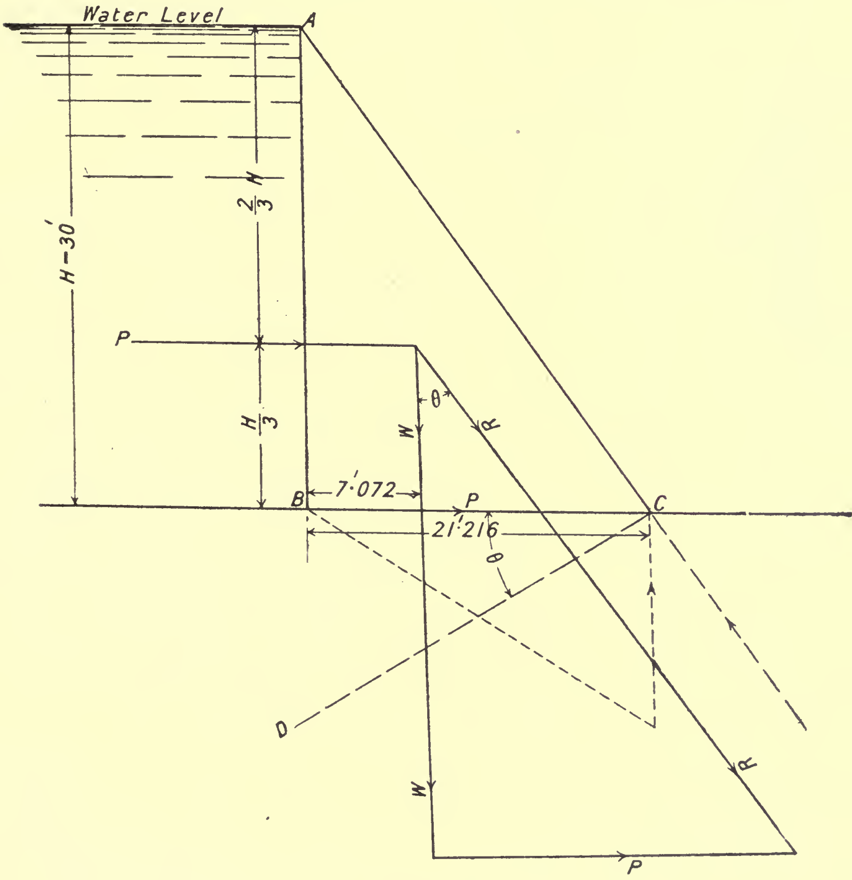


Fig. 26.

will equal $f \cos \theta$, the average intensity of pressure on

$$B\,C = \frac{f \cos \theta}{2}.$$

f = intensity of pressure in tons per square foot.

If we assume that $f = 5$ tons, and that the cosine of the angle $= 45°$, then

$$f \cos \theta = 5 \times \frac{1}{\sqrt{2}}$$

$$= 5 \times \frac{1}{1{\cdot}414}$$

$$= 3{\cdot}536 \text{ tons per square foot.}$$

The average intensity of pressure on B C will be

$$\frac{f \cos \theta}{2} = \frac{5}{1{\cdot}414} \div 2$$

$$= 1{\cdot}767 \text{ tons per square foot.}$$

Question 21.—A town is to be supplied with water from a river situated as shown in Fig. 27. The hill shown is just outside of the town, and much higher than the latter. Show by a sketch the outlines of a scheme which you consider would be suitable; give a brief description of this, and sketch in detail some portion of the works.

Answer.—A settling reservoir should be constructed where shown, near to the river, and a main laid to convey the water from the river to this tank; a further main should be laid from the settling reservoir to the filter beds, which should be constructed where shown (Fig. 28), and the water would flow by gravitation through this main. Near to the filters a pumping station would be erected, and suitable plant installed. The water would flow from the filter beds into the

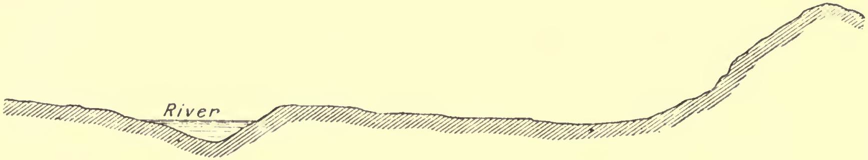


Fig. 27.

R. = River.
S.R. = Settling Reservoir.
F.B. = Filter Bed.
P.S. = Pumping Station.
S.R. = Service Reservoir.
D.M. = Delivery Main.
P.W. = Pump Well.

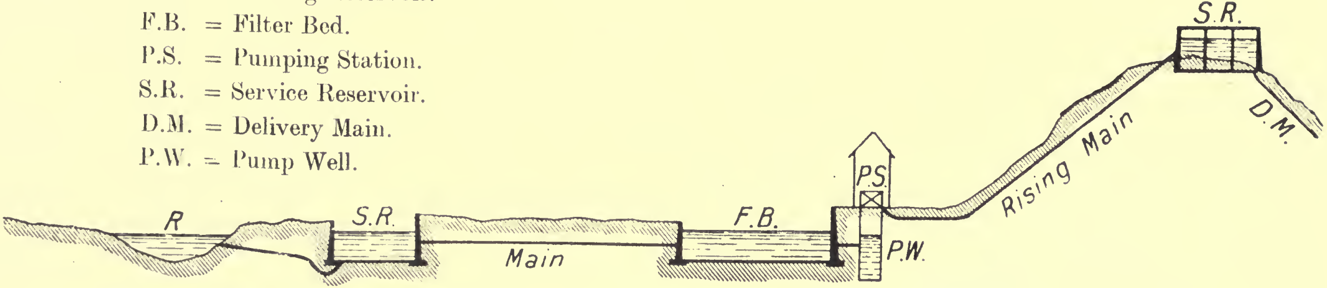


Fig. 28.

pump well, and would be pumped from this, through a rising main, into a service reservoir to be constructed on top of the hill, from whence it would flow by gravitation to the town. The inlet to the settling reservoir would be as shown in Fig. 29.

QUESTION 22.—Design a reinforced-concrete wall for a circular open reservoir 50 feet diameter, maximum depth of water in reservoir 10 feet. Show how you would calculate the tension in such a wall, and what

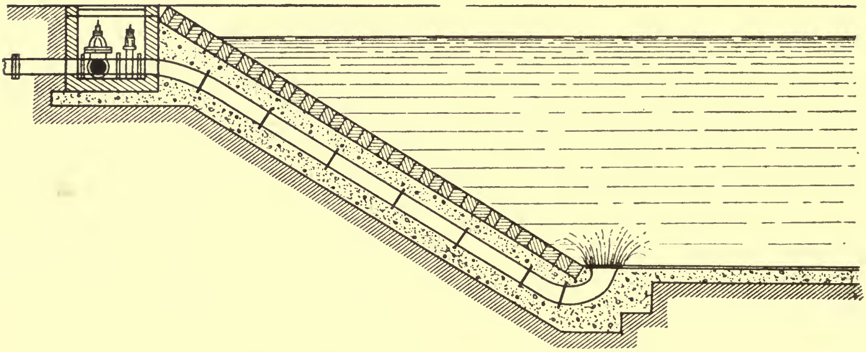


Fig. 29.—Settling Reservoir. Diagram showing Inlet and Reservoir Wall.

reinforcement you would insert to resist this. How would you treat the base of the wall, and the reservoir floor? What advantage has a circular reservoir over a rectangular one?

Answer.—Fig. 30 illustrates the wall recommended; it has a thickness at the base of 9 inches, and at the top of 6 inches, and is reinforced by the insertion of steel horizontal rings (or bars), and vertical bars on

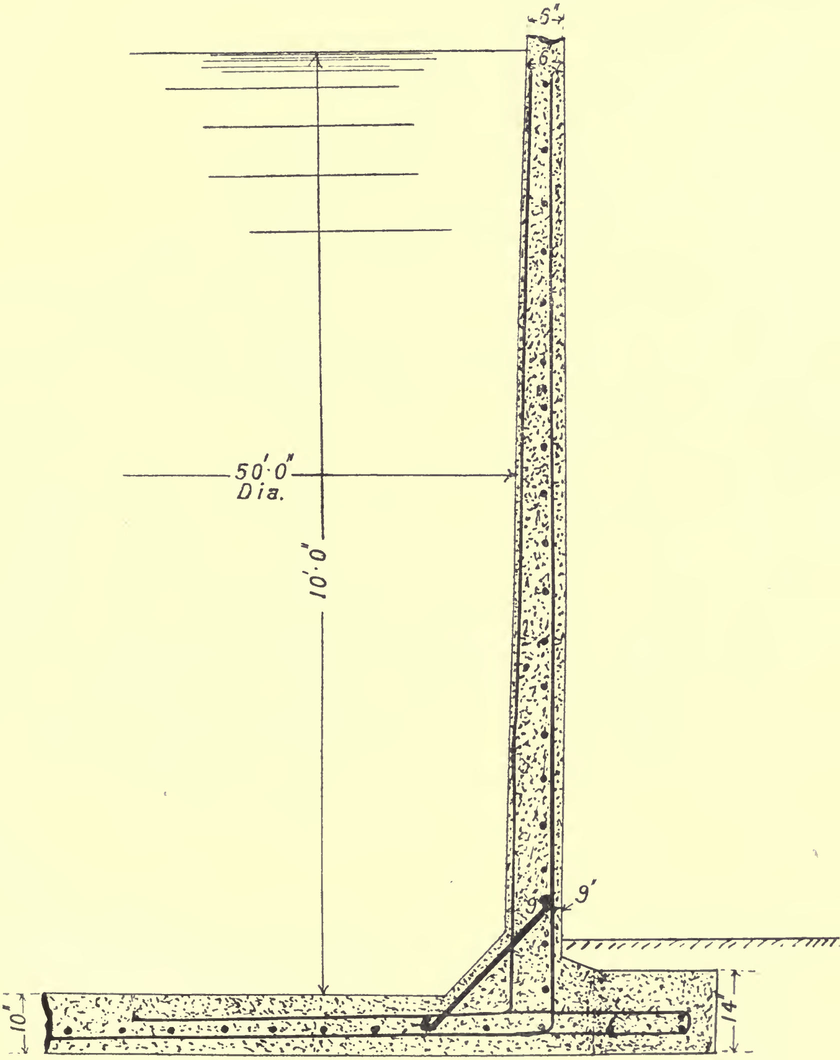


Fig. 30.—Reinforced Concrete Wall for Circular Reservoir.

inside and outside faces. The base of the wall is widened and specially reinforced as shown; the floor of the reservoir is 10 inches in thickness, and this is reinforced by the insertion of bars running at right angles to one another, and laced together where they cross.

The tension in the wall is calculated as follows :—

If d = internal diameter,

p = pressure of water at a certain depth,

then the tension in a ring of unit height, at that depth, will be

$$T = \frac{p\,d}{2}.$$

Thus, at the floor level in the reservoir now under consideration, the pressure is

$$p = 10 \times 62{\cdot}4 = 624 \text{ lbs.-feet}^2.$$

So that, if we imagine the reservoir to be cut into rings or horizontal planes 1 foot apart, the tension in the ring at the base of this reservoir (10 feet depth) will be

$$T = \frac{624 \times 50}{2} = 15{,}600 \text{ lbs.}$$

Assuming a stress of 12,000 lbs.-inches^2, the area of steel required in this bottom foot of the wall would be

$$A = \frac{15{,}600}{12{,}000} = 1{\cdot}3 \text{ inches}^2.$$

Horizontal bars 1 inch diameter, and placed at 6-inch centres will be quite sufficient reinforcement; but, there is no need for bars of this diameter where the

water pressure is less, higher up the wall, for, at a depth of 5 feet, for example, the tension = 7,800 lbs., and

$$A = \frac{7,800}{12,000} = 0{\cdot}65 \text{ inch}^2.$$

Two $\frac{1}{2}$-inch diameter steel bars (horizontal) at 6-inch centres at that height are ample. The reinforcement in the wall will, therefore, consist of horizontal bars, spaced at 6-inch centres, and varying in diameter from $\frac{1}{2}$ inch at the top of the wall to 1 inch at the base, the reinforcement in the floor consisting of $\frac{3}{4}$-inch bars spaced 1 foot apart, and laid at right angles to one another. If the ground is good, a plain concrete floor may be put in. It is advisable to insert vertical bars at the front and back of the wall, $\frac{1}{2}$-inch bars, placed 1 foot apart, will be sufficient.

A circular reservoir is less expensive than a rectangular one, probably costing 25 per cent. less; it is only recommended for small reservoirs; they are sometimes built entirely above ground, as the one now being discussed, and often partially so, or occasionally completely below ground. The circular centering is costly. Many reservoirs of this type have been constructed in America, and they possess the advantage of having no angles.

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